11

Electric Wheelchair Navigation Simulators: why, when, how?

Patrick Abellard, Iadaloharivola Randria, Alexandre Abellard, Mohamed Moncef Ben Khelifa and Pascal Ramanantsizehena
HANDIBIO EA4322, IUT, Université du Sud Toulon Var / Ecole Supérieure Polytechnique d'Anatananarivo
France / Madagascar

1. Introduction

It is now widely admitted that every assistive technical system has to be evaluated so as to fit the user's needs. Tests in realistic situation provide pertinent indications concerning a user's adaptation to a new technical assistance.
However, they are often a costly solution as their usual drawback is to be very specific to each handicap or each person. Furthermore, the acceptability and appropriaton of any new technical assistance has to be insured. In fact, it is not only a question of proposing technological solutions to a disabled person so that it can gain some autonomy, but also to integrate a human dimension in their choice (Pan et al., 2006). In this context, one challenge that is faced by the international community to bring it answers is the evaluation of motor and cognitive capacitied in the choice of a technical help. Some of these works propose evaluation methods based on questionnaires or usability clinical tests (Kirby et al., 2002).
The main drawback of these solutions is that they are often subjective, dedicated to a specific pathology and are not sufficient to make the final choice adapted to the motor and psychological user specificities. The decision then relies on doctors expertise, particularly ergotherapists. In the case of an electric wheelchair, this choice is all the more delicate that it makes up a complex motorized technical help, inevitably driving to safety, ergonomy and penibility problems. The necessity to propose an evaluation tool that does not subsitute to the ergotherapist expertise, but rather complete it, becomes therefore pertinent, all the more that tests in real situation can by costly since often very specific (Roussel, 2002). In this context, three point must be studied with a particular attention :

- disabled person fatigability
- material financial cost
- risks for the disabled person and the environment (accident, collision...)

In fact, concentration asked to a disabled person during navigation experiments quickly implies a fatigue, and these are precisely the most disabled persons that generally need the more assistive tools which are the most costly. Moreover, as the more disabled person have the highest risks when driving a wheelchair, the prescription of a wheelchair required many cares from the team made of a prescribing doctor, an ergotherapist (and/or

psychomotrician) and the user. In this aim, the team has to globally evaluate the user capacities so as to determine the most appropriated wheelchair to his handicap and his navigation environment. This evaluation includes various exercises similar to those encountered in a daily wheelchair use.
Sometimes, the prescription of an electric wheelchair can be refused to a disabled person for safety or apprehension reasons. It becomes therefore impossible to evaluate the help that could be brought by technical assistance. Thus, simulation exercises in a virtual environment are an interesting solution, since they enable :

- to reduce previous constraints
- to bring a solution to the safety problem
- to diversify experiments
- to evaluate driving capacities
- to quantify needs in terms of functionnalities

Several research teams have worked on wheelchair driving simulators prototypes developments.

2. Electric wheelchair simulators

Scientific and research communities have often tried to put technologies for human self being for decades. In the early 80s, Pronk and his mates have been the first to develop a simulation tool for electric wheelchair driving (Pronk *et al.*, 1980). In this aim, they used computer assisted simulation. A global "bird's-eye" view of the wheelchair movement was shown on a terminal screen. Authors concluded that the simulator could constitute in the future a pertinent help for evaluation and/or adaptation of electric wheelchairs. Since these first works, several other projects have exploited this idea to use virtual reality for electric wheelchair driving learning.

2.1 PWMS (Powered Wheelchair Mobility Simulator): State University of New York (Buffalo), USA

This electric wheelchair simulator project is based on original works from « Turtle Trainer » (Fig. 1), (Bresler, 1990), developed by a team from the Center for Assistive Technology at the State University of New York (Buffalo), so as to build an evaluation and formation tool for people with important physical disabilities and cognitive and/or sensorial deficiencies (Schmeler et al., 1993). This realization consists in a motorized platform on which a manual wheelchair is brought in order to evaluate driving capacities of a real electric wheelchair.
A performance validation study has been done on this prototype so as to determine its viability as a movement and command simulator. Performance has been compared to the one obtained with a real wheelchair and experienced users on a trajectory composed of several tasks and measurements. Results proved statistical and clinical similarity between the two methods, justifying that the simulator would enable a identical behaviour.
This work led to the realization of PWMS platform for clinicians and patients. It is devoted to become an evaluation and learning tool for determining electric wheelchair driving capacities of people with physical, cognitive and/or sensorial disabilities, having a manual wheelchair but unable to use it (Schmeler, 1993).

Fig. 1. Turtle trainer

2.2 Virtual Electric Power Wheelchair Driving: Pittsburgh University & VA Healthcare System, Pennsylvania, USA

This is a study in which real-time speed control of an electric wheelchair has been analyzed facing perturbations, internal parameters variations and external uncertaintities (Ding et al., 2003). Researchers have done this study since simple Proportional-Integral controller used in motorized wheelchairs has been considered insufficient and does not behave correctly with perturbations, sensors uncertainties and load variations. This team thus proposed a robust adaptive controller with which system stability and speed errors convergence have been examined. Controller efficiency has been validated by simulation studies. Authors think this study could lead to driving improvements, more fluidity sensations and few collisions.

They are actually investing many efforts to develop environments and virtual systems in order to improve evaluation and mobility learning, as well as environment perception (Fig. 2).

The resulting system brings wheelchair users a formation tool in various environments without any risk (no physical constrains such as walls, furniture, stairs, no surfance unevenness, no road traffic...).

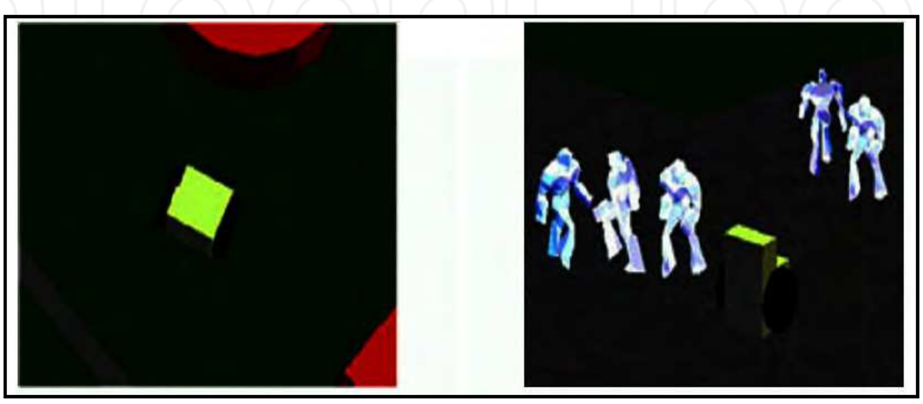

Fig. 2. 3D environment static (left) and dynamic (right) views

A following work on virtual reality potentialities for rehabilitation, formation and motorized wheelchair driving training has been developped (Cooper et al., 2005). The aim is to enable users to drive with any risk and efficiently in a virtual environment using a lever.
The context of virtual learning includes simple scenarii simulating basic motor takes, and complex dynamic scenarii simulating movements on a pavement with people walking around. Clinicians can change virtual scenarii in order to define specific tasks and can record formation progression.
Virtual formation platform is made of 3 modules : static environment, dynamic environment, evaluation. The first module enables the virtual wheelchair movement in a nempty 3D environment or with simple static scenarii simulating basic motor tasks. The second one simulates the wheelchair evolving on a sidewalk surrounded by walkers and examinates attention and complex context training capacities. The third module records virtual wheelchair speed and position, as well as virtual walkers. Number of collisions, formation scenario execution time and trajectory performed are also recorded (Marchuk et al., 2007). Data can be used to analyze formation effects or as evaluation criteria.

2.3 Wheelchair User Proficiency Through Virtual Simulation: OSC (Ohio Supercomputer Center) and Ohio State University, USA

The basic idea was to conceive a system enabling a user to drive a motorized wheelchair in a virtual architectural environment (Swan et al., 1994). In fact, lack of evaluation methods for disabled person for defining the best suited appropriated command were often reported. However :

- technology evolutions then enabled to make control mechanisms more performant,
- the « Americans with Disabilities Act » (ADA, 1990) legally made an obligation to almost all public structures to become accessible to disabled persons.

In order to be free from difficulties linked to the limitation of users to real wheelchair training, the developed system uses virtual reality to evaluate the user competency evolving into virtual structured environments. It is composed of an instrumented electric wheelchair linked to a workstation to simulate real speed and orientation from an architectural database. Display is done inside and outside via stereoscopic vision using polarized lens (Fig. 3). A hierarchical data structure enables to detect collisions between the virtual wheelchair and the environment. This system can be useful for wheelchair users going to public structures as well as architects and conceivers, since it provides structures visualization and a mean to study its ADA conformity (Carlson et al., 1994).
The Rehabilitation Engineering Center for the Quantification of Physical Performance from Ohio State University and the OSC (Ohio Supercomputer Center) in Colombus collaborated in order to take part in the development of the virtual world prototyping system enabling the electric wheelchair navigation (Fig. 4) under the direction of Dr. Wayne Carlson, "Advanced Computing Center for the Arts and Design" director, et de Don Stredney from « Ohio Supercomputer Center ».

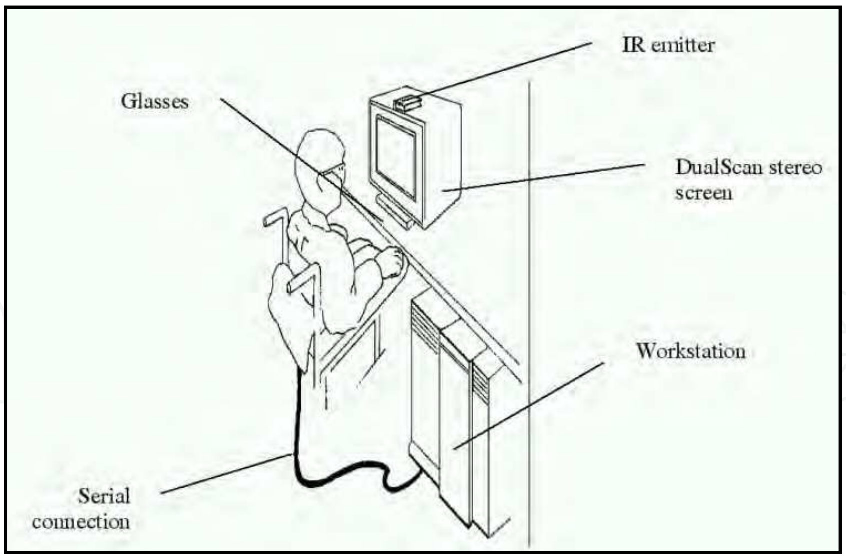

Fig. 3. System configuration

A sub-project named " The determination of wheelchair user proficiency and environmental accessibility through virtual simulation" (Swan et al., 1994) is designed to examine human activity in free environments navigation, by using virtual simulations generated with computers, so as to provide pertinent information in order to define the most suited technological assistances to a specific disabled person. Furthermore, this research aims at validating direct applications of developped optimized method for the design of secured environments.

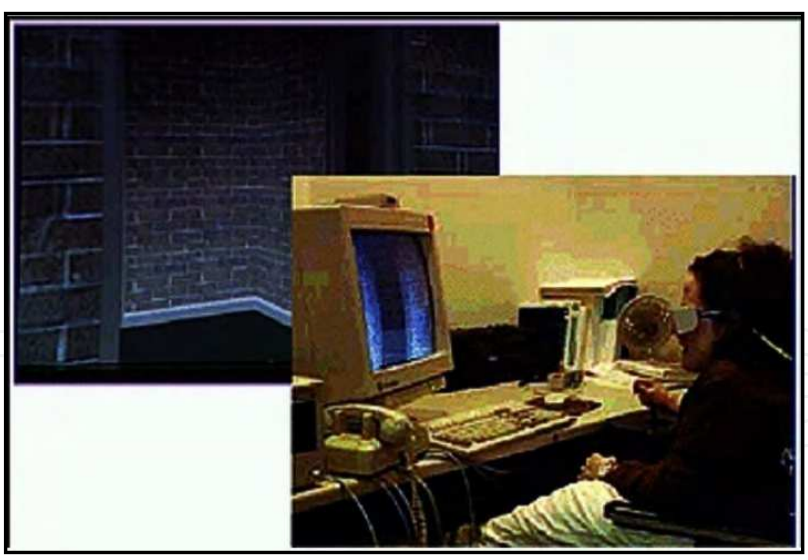
Fig. 4. Virtual wheelchair simulation

This project combines the expertise of Ohio State University researchers with Invacare Corporation competencies - a leader in assistive technologies design. This projet not only provides essential information on design and technology use for the best suited control, but it also constitutes a system to train users of such systems. Besides, the developped system can be used by architects, conceivers and builders so as to insure unlimited access to environments by the disabled person (public buildings, commercial centers, homes and offices, shops, etc.)

2.4 Wheelchair Training: Virtual Reality Laboratory, ORI (Oregon Research Institute), Oregon, USA

Oregon Research Institute (ORI) researchers have been among the first ones to use virtual reality to learn motor habilities to disabled children. They used this method to increase blind and deaf children mobility by training them to efficiently use their wheelchairs. In this project, the computer-generated environment simulates a street with people so that the child could have more experience as a wheelchair driver. Actually, researchers develop a set of education and rehabilitation tools for disabled persons. It is based on an experimental study to take into account specific consequences of different kinds of navigation learning on children using virtual reality.
This project also proposes the use of virtual reality to improve spatial perception through the movements (Inman & Loge, 1995), for instance by using "crash" sounns when collisions occur. The study can be based on three scenarii depending on motivation and personal rythm of evaluated patients. It aims at bringing secure navigation and experience to the user. This project proves the usefulness of virtual reality for children suffering from severe physical disabilities. With virtual reality, it is now possible to provide exploration and action on physical environment opportunities, in order to gain mobility competencies, i.e. cognitive strategies and perception capacities that can only be learnt from an initial experiment. In the simulator, a sound feedback has been also integrated for blind people (Inman et al., 2000).

2.5 H.M2.P.H.(Habitat Modulable et Mobile pour Personnes Handicapées): Tours University, France.

HM2PH project funded by Indre-et-Loire Conseil Général results from a collaboration between Computer Science Department Polytech'Tours Engineering School and HaNT (Handicap et Nouvelles Technologies) research team from Tours University LI Laboratory. It aims at bringing disabled (and elderly) people an autonomy gain thanks to adapted technical assistances. It also concerns the design of an adapted home :

- that can be inserted in a medical place (hospital, rehabilitation center)
- that can be brought at home

This project is related to a PhD work (Leloup, 2004) on « Software tools for assisted conception of adapted home ». Its aim is to specify and realize a software tool enabling to quickly conceive an adapted home for a disabled person. HM2PH 2D plans can be created and each room can be customized while respecting three kinds of constraints :

- constraints related to classic architecture and production costs (fixed HM2PH dimensions, water pipes optimizing…),
- architecture constraints for building where disabled people live (corridors with, rotation areas for wheelchair, rooms minimal dimensions…)
- preferences of the future resident (proximity of rooms, topography and specific distribution of each room, reduction or enlargement of some rooms…).

Difficulty is therefore to find different organization that satisfy these constraints the best way possible. Obtained results enable to generate a set of plans that take into account all

these constraints efficiently. This work is currently in progress in another PhD that started on same topics to have more precise results and to extend the nature of constraints by making the most of different modules.
In order to give a possibility to appreciate organization and equipments generated by the MoGAP (Moteur de Génération de Plans or Plan Generator Engine), it seemed interesting to make a 3D real time virtual visit from the 2D plan (Fig. 5). Simulation issues are important, since it must provide a maximal realism so that the user could have the feeling to be in his future home, and that he can appreciate aesthetics and functionalities. It is thus planned that the user can test different virtual equipments included in the scene. Moreover, visit includes collision detection that enable to test and validate home circulation conditions.
Conception assistive software deals with plan automated generation. Obtained result is used to build a 3D world for H2MPH virtual visit (Fig. 6). In order to satisfy the person in the concerned living space, it is necessary to put in place and activate services of life quality thanks to Technical Help Database.

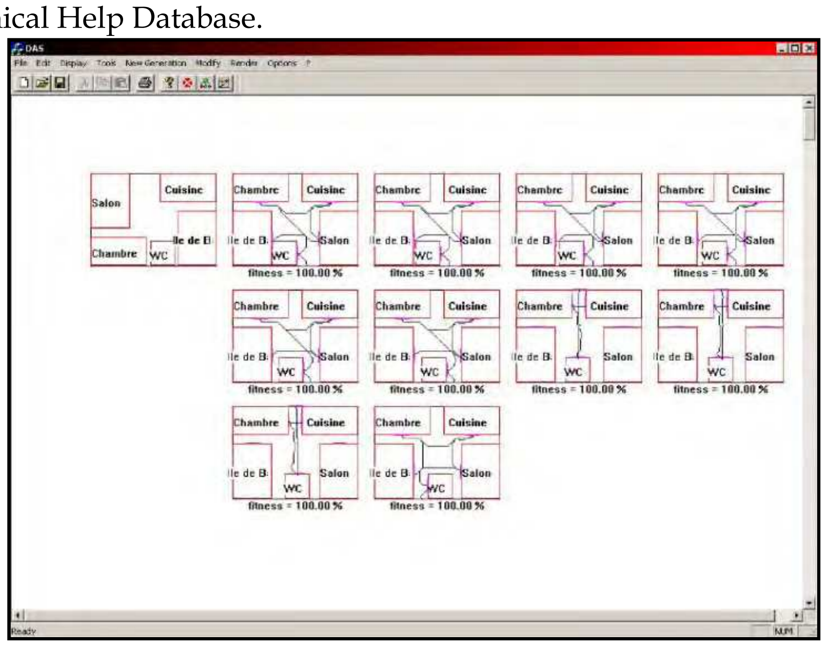

Fig. 5. 2D map automatic generation

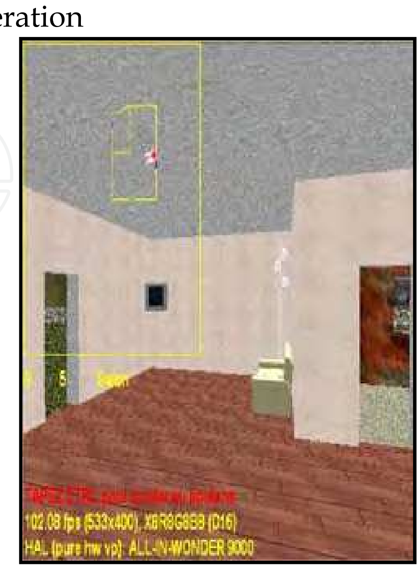

Fig. 6. 3D virtual visit

2.6 Assistive Technology Access Interfaces: Ohn School for the Physically Disabled, Tel Aviv, Israel.

This project is part of an investigating research field for developing and evaluating technological assistive interfaces so that people with severe physical incapacities to use more efficiently and with less fatigue their residual motor capacities. It aims at testing the capacity of a basic driving simulator software to evaluate and train disabled children to command an electric wheelchair (Hasdai et al., 1998).

An evaluation scale of considered capacities necessary to insure safety and command efficiency has been defined. Children with ages ranging from 7 to 22 suffering either from progressive muscular dystrophy or a cerebral palsy have been evaluated in their capacity of controlling an electric wheelchair. They have been divided in two groups : with or without previous experience.

After evaluation on a real wheelchair, unexperienced people have been trained on a computer game using a lever in which they evolved in labyrinths similar to the disposition of their own school environment. Another test labyrinth is then presented to them, before been evaluated on their wheelchair control capacities.

Research conductors noticed that althouigh being inferior to those of experienced drivers, unexperienced children have significantly increased their driving performances during the learning phase, hence their conclusion that a simulator software could help to develop and evaluate capacities required to drive an electric wheelchair.

2.7 Simulator of Powered Wheelchair: Research Institute, National Rehabilitation Center for the Disabled, Japan.

The context of study is the development and practical use of an outside environment simulator for an electric wheelchair. The simulator is made of two computer screens and a mobile platform (Fig. 7). Screens supply a virtual environment including road signs, railroads crossing, sidewalks, sloping ground… Walkers and bicycles can come in different ways and paths. Platform is connected to six actuators (i.e. electric servo-motors) producing accelerations and decelerations similar to those of a real electric wheelchair.

Fig. 7. Wheelchair driving simulator first version

15 persons tested the simulator. Results showed that users found many similarities between real and virtual drivings, despite having more difficulties when using the simulator. This has been caused by the lack of a lateral view and vestibular disease that has been felt by approximately half of the users. This point deserves a particular attention, particularly for first tests. Furthermore, researchers performed tests with a person having physical and mental disabilities to learn how to control a wheelchair with the simulator, but he lacked comprehension, concentration and motivation. A first attempt to actuate a sole switch to drive the simulator proved he could understand the system and focus his attention on the task to perform. Next attempt requiring two driving switches showed he could not stop when a collision risk occurred.
A head control has therefore been added, which showed in a last test that driving could be planned once safety problem was solved. This first simulation of the simulator has been considered efficient to determine if someone with important disabilities could drive an electric wheelchair or not, but decision is conditioned by a very good knowledge of the accompanying team in terms of technology. System evolutions drove to a new version (Niniss & Inoue, 2005) in which the most important modification was to replace the two screens display system with a hemispheric display proving a 110° field of vision (Fig. 8). Consequently, latest experiments drove to the definition of qualitative and quantitative evaluation criteria, which seem efficient when correctly combined.

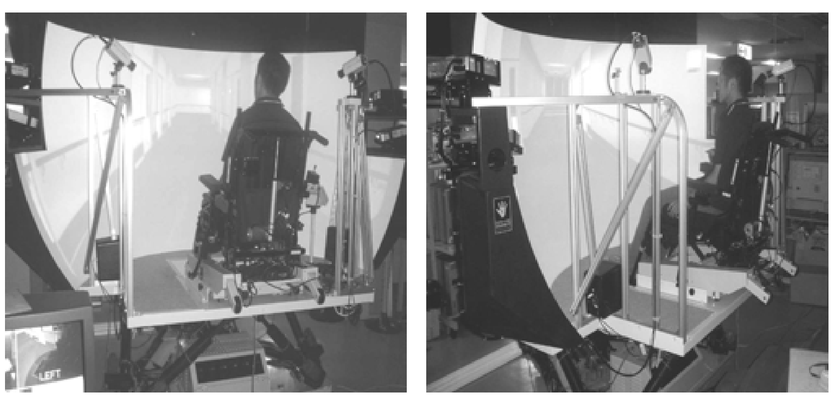

Fig. 8. Wheelchair driving simulator second version

2.8 Electric wheelchair Simulation, VAHM extension: LASC (Laboratoire d'Automatique des Systèmes Coopératifs), Metz University, France

This project is made of a simulation platform using virtual reality, where a wheelchair is placed (Fig. 9). It has three aims (Niniss et al., 2000a) :

- helping conceiving new mobility assistance functionnalities,
- helping choosing and prescribing electric wheelchairs,
- making driving learning easier

This work is an improvement of a previous project : VAHM (Véhicule Autonome pour Handicapés Moteurs) (Bourhis et al., 1998). It takes into account kinematics of an existing intelligent electric wheelchair, that has been conceived to ease driving learning (Niniss et al., 2000b). It also integrated the modeling of ultrasonic sensors in simulation and an intelligent system to help the driver controlling the motorized wheelchair.

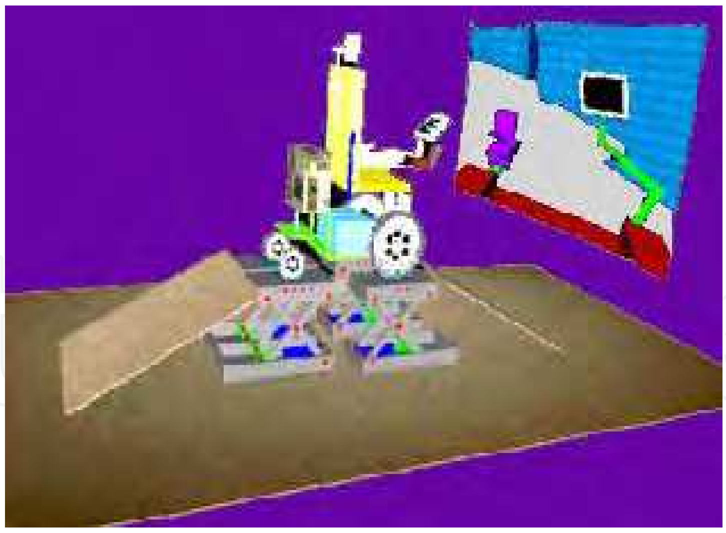

Fig. 9. Simulation platform

Virtual reality system is here conceived to help the best suited assistance to locomotor assistance of any patient (Niniss & Nadif, 2003). The most important element of the systemis the simulator that controls the virtual world and its interactions with the real world. System includes a platform with a fixed base with a rigid structure to support the wheelchair. Two pairs of rolls enable motor wheels to turn freely while wheelchair frame remains fixed. In order to establish evaluation criteria, a test protocol has been defined. A test group is composed of good-health people, that have been divided in two sub-groups depending on their electric wheelchair knowledge.

Three wheelchairs have been used : Storm (Invacare), Moover95 (Flex) and Jet 2 (Pride Mobility). First, a global view of the environment and the virtual wheelchair has been presented to users, who had 5 minutes to freely explore it. Then, the research team analyzed quantitative and qualitative data obtained concerning users' capacities based on their evaluation in virtual reality. A second evaluation with disabled people is necessary before system conceivers approval. In this aim, a future foreseen evolution of this simulator will integrate the recording of several information and evaluation elements (duration and number of collisions and stops, environmental occupation…) (Dir et al., 2008; Niniss et al., 2004).

2.9 Evaluating and learning to drive an electric wheelchair: Royal Hospital for Neuro-disability & University of East London, Londres, UK.

This work results from the collaboration between the Department of Clinical Psychology (Astley Ainslie Hospital, Edinburgh), Department of Technology Clinic (Royal Hospital for Neuro-disability, West Hill) and the Psychology Department (East London University).

The first studies (Harrison et al., 2000) presented quantitative and qualitative data relative to conception and implementation of two non immersive virtual environments so as to evaluate and train adult electric wheelchair users having complex neurologic deficiencies. Manoeuvre and itinerary search capacities have been more particularly analyzed. Results showed that attendees consider the virtual environment to be realistic and representative, and that tasks are a good reflect of required capacities to drive an electric wheelchair but that the execution of manœuvrability tasks is more difficult in the simulator than in real life.

A second study then followed (Harrison et al., 2002) on system control efficiency so as to avoid touching obstacles manœuvrability and itinerary seeking capacity in a complex environment planification. Six unexperienced users participated to the project, either by avoiding an obstacle or planning a trajectory. Performance measures have been recorded in reality before and after learning phases and during virtual reality sessions. Questions about virtual environment aesthetics and simulator functional aspects have also been asked to users. Answers were globally positive. However, they found again manœuvrability tasks far more difficult in virtual reality than in reality, and put the light on some simulator command difficulties and various improvements to perform on both virtual and real tasks have been noted.
As a conclusion, authors said both chosen virtual environments showed potentially useful means for evaluating and training inexperienced users. However, they should be still improved so as to reinforce users motivation and improve their capacities.

2.10 Dynamic System Engineering Research Group, Portsmouth University, UK

This team worked on wheelchair obstacles avoidance, by using virtual reality for helping elderly people who have learning problems for manipulating a mobility system (Stott et al., 2000). The goal is to study different learning applications using virtual reality and their clinical involving for patients suffering from mobility problems. In this aim, automatized literature seeking has been performed using databases from MEDLINE, Cochrane, CIRRIE and REHABDATA. Three studies subcategories have been defined : five related to a training leading to qualifications, two "to physical exercises formation", and one to leisure activities. They proved interesting transfer of the learning from the virtual environment to the real use of mobility systems.

2.11 VEMS (Virtual Environment Mobility Simulator): Limerick University, Ireland

VEMS stands for Virtual Environment Mobility Simulator. Its development aims at providing simple and efficient solutions for learning and readaptation to drive an electric wheelchair (Adelola et al., 2002; Adelola et al., 2005a). Its main interest is analysis of manipulation effects of a real wheelchair to interact with an environment, since childhood development is strongly related to exploration and action with environment. This system provides a virtual and familiar environmental context on a computer screen and proposes simple tasks with various game elements to motivate the user (Fig. 10). The very diversified nature of the incapacities nevertheless requires system adaptability to each user specific needs. It uses a joint analysis technique to learn comportements, preferences and incapacites of the users to fulfill their conditions in order to have an efficient learning.
VEMS is still developed at Limerick University (Ireland) in order to obtain a virtual environment better adapted to both learning and patient disabilities, so that he could have better results in shorter time during context changes (Adelola et al.., 2003a). In fact, important waiting times between sessions can not reasonably occur with patients having an important fatigability.

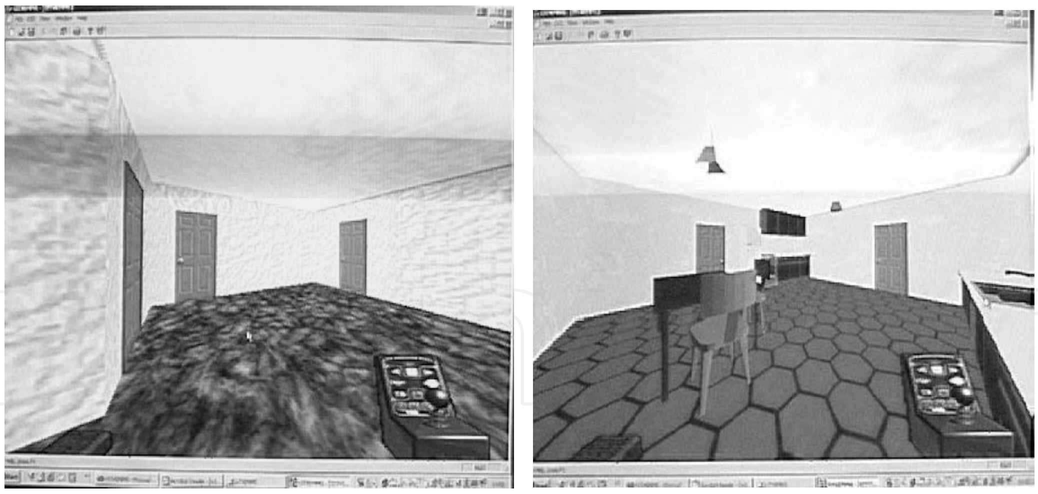

Fig. 10. Domestic environment VEMS view : corridor (left) kitchen (right)

VEMS is adaptive in its constitutive elements sizes (Adelola et al., 2003b) and enables to help children gaining some capacities by using a sure and safe virtual reality system thanks to :

- the study of an experimental and statistical method to measure qualifications required to drive a wheelchair in a virtual environment,
- the elaboration of an analytical procedure to obtain mathematical models of the behavior of a user in phase of learning to virtual environment modifications performance and user behaviour on optimal models evaluation and prediction

Evaluation by initial simulation uses joint analysis taking into account subjective answers, including patient reaction to demands done during wheelchair driving in various environments and circumstances. Authors conclude that virtual reality system is interesting for wheelchair driving learning. In fact, researches proved children with short attention times can be encouraged to use virtual reality, since virtual environments can easily captivate their attention. Virtual game conception is currently studied since it could enable children to use an electric wheelchair in several different virtual environments (Adelola *et al.*, 2005b).

One of the project most recent steps is the conception of a monitoring network in a Virtual Environment Simulator (VES) for motorized wheelchair drivers training (Dholkawala et al., 2005). Virtual environment enables therapists and welfare workers to watch and monitor the training process on a distant site, since some children are more at ease alone even if they require some supervision. The VES frame enables to provide a help to users if necessary. Improvements to its graphical interface are currently being studied.

2.12 OCAWUP (Obstacle Course Assessment of Wheelchair User Performance): Laval and Sherbrooke Universities, Québec, Canada.

It's a collaborative project between several Canadian rehabilitation centers and institutes, hospitals and universities working on assistive technologies. It deals with wheelchair navigation evaluation. In fact, authors think results obtained for clinically evaluate wheelchair users capacities and parameters which has influence on mobility are not complete enough. Initial work has therefore consisted in defining a conceptual frame that suggests a more global view for evaluating wheelchair driving capacity (Routhier et al., 2003). In this aim, after selecting the factors that are suspected to influence wheelchair mobility, a conceptual frame has been defined to enable a precise examination of obtained results. Fine analysis of evaluation tools enabled to determine factors to consider in clinical evaluation of wheelchair mobility capacity, so as to develop a normalized method usable in hospitals.

Future improvements should concern additional factors conditionning mobility such as users profiles, environment complete characteristics, patients daily activities, social roles and received training. Analysis of results on a standardized route with normalized basic situation should enable rehabilitation therapists to evaluate patients for choosing a wheelchair and to note their progressions during the learning phase. Moreover, this tool should allow to predict results for daily activities.

Next steps for this study will also be on the development of a test to evaluate and record manual and motorized wheelchairs driving in a normalized context and in potentially difficult environmental situations. Authors particularly worked on the use of the validity process for obstacle choice and notation system. Specific obstacles include corridors, doors, sidewalks, smooth or damaged surfaces, slopes… Experts (ergotherapists, researchers, etc.) considered these choices to be representative of daily life situation. Authors hope OCAWUP will help clinicians in their interventions with patients to improve their participation in social activities (Routhier et al., 2004).

2.13 Accessibility haptic interface: Strathclyde University, Glasgow, Scotland, UK

Interest to life quality and respect of the law on disabled persons discrimination (DDA: Disability Discrimination Act (DDA, 1995) led to establish accessibility as a priority in recent constructions. In this context, a recent project from Strathclyde University concerned the development of a wheelchair platform (Grant et al., 2004) which is a virtual reality service that can be used to address buildings accessibility questions (Grant, 2003). This work is the result of collaboration between architects, biomechanicians and users, and consist in the study of materials related to conception and construction of the platform, test interfaces, and users evaluation. Research is oriented to a prototype development, extending existing simulation and exploration possibilities for a use in building conception (Fig. 11).

Project results led to the development a haptic interface so that wheelchair users could move into virtual buildings using their own wheelchair. This interface main point is that it provides the user a retroaction related to the required effort to drive wheelchair through surface changes and slopes This has been followed by the production of tools aiming at solving accessibility conception problems. Strathclyde University tried to combine advances graphics with a haptic interface in order to build a wheelchair platform able to simulation navigation in virtual buildings (Grant et al., 2005). This approach is one of the more sophisticated existing. Nevertheless, all problems encountered by a conceiver from access and environment interaction have not been solved yet.

Fig. 11. Simulation platform for manual and electric wheelchair

2.14 VRWC (Virtual Reality Wheelchair): Clarkson University, New York, USA.

VRWC project deals with conception and realization of every parts of a manual wheelchair driving simulator (Baran et al., 2004). The price of an electric wheelchair can go up to $20.000,which is prohibitive for insure companies to help financing an acquisition to a child that has not showed yet driving skills. This simulator is used to train someone to efficiently control a wheelchair in a sure virtual environment, under supervising of a therapist. If this simulation is very precise, and that training proved to be efficient, the next step will be to make it accepted by insurance companies as a training for driving an electric wheelchair. Thus, families would obtain facilities for buying wheelchairs to their children.

This project uses a code that could transform a group of objects to detect collisions (for example). Collision detection and slope monitoring are possible thanks to a set of segments materializing a field contact (horizontal for obstacles, vertical for the ground) (Fig. 12). Interactions with virtual world are done with a lever, a video-tracker and a 6-DOF platform.

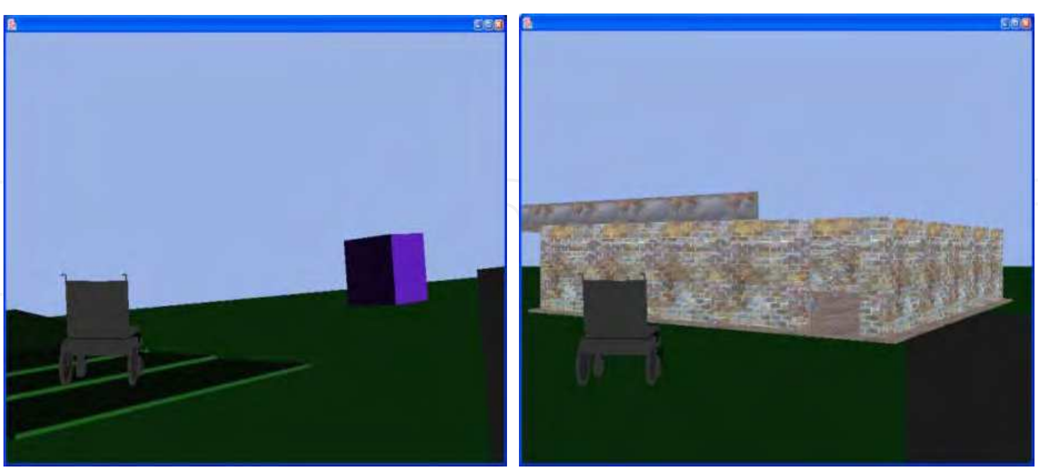

Fig. 12. Virtual Reality Wheelchair

For many people with physical and/or cognitive deficiencies, assistance engineering provided thanks to a powered wheelchair (PWC) solutions for mobilty in both personal and professional areas. However, in spite of independence provided by a PWC, indemnifying

organisms are often not disposed to finance its acquisition as long as the concerned person did not prove his capacity to command the wheelchair by himself.
Learning methods for manipulating electric wheelchairs are expensive and potentially unsafe. Virtal reality technology can therefore provide a learning tool, an efficient method and an information source on wheelchair driving capacities (Harrison et al., 2000), (Hasdai et al., 1998). Current VPW/C evolutions (Virtual Power WheelChair) aim at conceiving and realizing a power wheelchair providing precise visual, proprioceptive and vestibular information feedback in order to exactly simulate navigation for learning needs (Sonar et al., 2005).

2.15 Stroke Simulator : VRlab/HPC2N, Umeå University, Sweden

Initial goals were to study virtual environments capacities to influence social worker apathy (Maxhall et al., 2004). 9 persons from Norrland Universitary Hospital (NUS) perform three daily tasks such as reading a newspaper, filling a glass with water and putting toothpaste on a toothbrush. These tasks have been done in a virtual environment with both sane people and patiens suffering from tremors. The considered virtual environment was a normal flat that could be adapted to any perceptual disorder (Fig. 13).

Fig. 13. Normal and tremors view

Observation and interview results showed that the simulator, despite usability problems, was efficient to influence social workers empathy. Since this time, the team is developing a real time 3D environment Colosseum3D (Backman, 2005) which architecture enable to easily create rich environments with rigid elements dynamics, 3D results using OpenGL Shaders, 3D sound and human avatars (Fig. 14).

Fig. 14. Stroke Simulator : manipulating items and virtual environment view

2.16 Virtual Intelligent Wheelchair: CRVM (Centre de Réalité Virtuelle de la Méditerranée), Mediterranean University, Marseille, France

This team is currently developing a learning and evaluation simulator in the CRVM where a CAVE system has recently been installed so as to perform optimal immersion (Mestre et al., 2007). This interactive simulator will enable to optimize graphic and command interfaces, and human-machine cooperation by taking into account potential difficulties resulting from their sophistication (Mestre, 2004). It is also developed to become a learning system for commanding a virtual wheelchair, and an assistive tool for prescribing a wheelchair adapted to a specific user (Fig. 15).

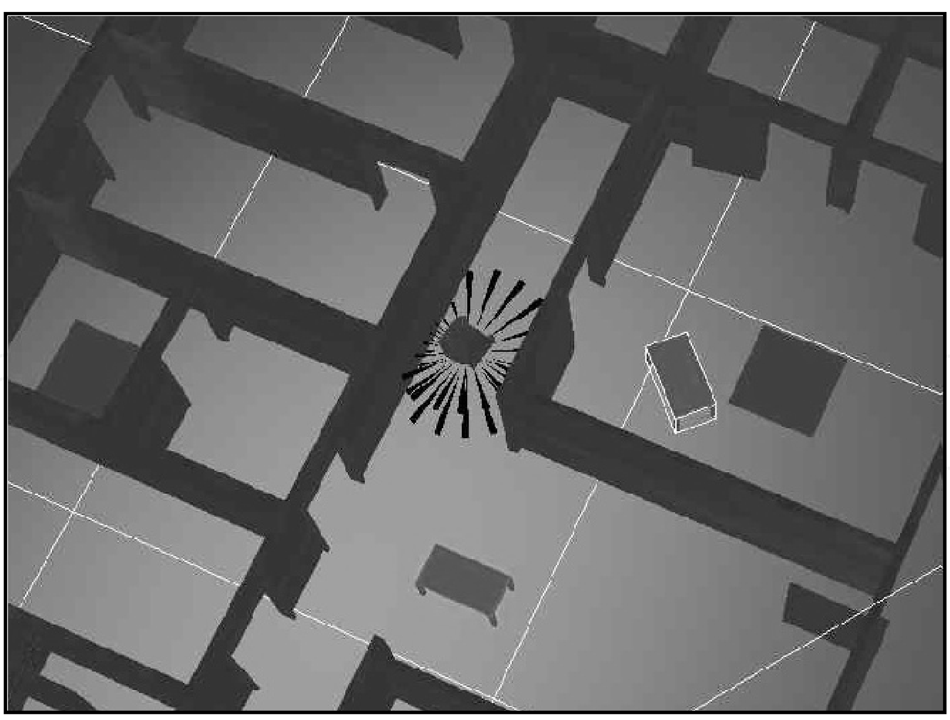
Fig. 15. 3D intelligent wheelchair simulation with proximity sensors

More precisely, experiments are done by using a virtual wheelchair dynamic model using Virtools SKD (studies using real experimental intelligent wheelchair are planned) (Mestre et al., 2006). In previous works, wheelchair had a completely automated movement from its start to the end of the trajectory, while it is now necessary to consider an active patient.

2.17 Home electric wheelchair simulator: LISV (Laboratoire d'Ingénierie des Systèmes de Versailles), Versailles University, France

It is a simulation project of wheelchair navigation for a better building accessibility (Taychouri et al., 2008). In fact, adapting spaces of residential and industrial. In this complex and diversified context, space accessibility in wheelchair is a very interesting topic. The goal is there to make easier movings inside or outside homes. Proposed methodology consists in evaluating movings of wheelchair in a domestic place. Problem not only includes trajectories generation, but also their evaluation based on distance and time, trajectory curves, maneuverability and driving quality.

2.18 WheelSim © : LifeTool, Austria

This software is the only one dealing with commercial wheelchair simulation available on the market. WheelSim © is a product from LifeTool society (f. 1998), based in Linz, Austria. Software released version is now 1.2 and aims at adapting technology to human. This society unites competencies of diversified specialists, combining educative, psychological, social and realistic integrative of social organisms members with technical expertise of engineering researchers and specialists of disabilities and rehabilitation.
WheelSim software aims at making easier the learning of power wheelchair driving, and can also be used as a diagnosis and training software or even as a simple game.
Software aims at improving both personal mobility or circulation safety. The fact that learning system efficient command enable to move safely in circulation is however questionable, as several other factors have to be taken into account and rigourously integrated before taking decisions of moving capacities. Wheelchair can be commanded with a joystick, keyboard arrow keys or with contactors. Navigation levels can be very diversified in situation and complexity (Fig. 16).

Fig. 16. WheelSim navigation

WheelSim also includes fault notion, i.e. deviations from yellow lines showing security limits, navigation collisions, or circulation rules respect. Faults are quantified, indicated by visual feedbacks and can induce up to disqualification (navigation stop). Applications can concern rehabilitation, childhood, physical and/or mental disabililty, game of skills...

2.19 ISIDORE (Interface d'aide à la SImulation, à la DécisiOn et la REéducation), HandiBio, Toulon University , France

ISIDORE has been developped in partnership with Hôpital Renée Sabran (Giens/Hyères – Var) and Association des Paralysés de France (Var delegation). It is useful for learning and evaluating driving capacity for electric wheelchair prescription. It provides quantitative information to help therapist in decision making for user progressions and the instrumentation to be added for a safe driving. In this aim, it integrates reference comportemental information with a fuzzy approach (Randria et al, 2008a).
In order to obtain a reference trajectory, ISIDORE uses a genetic or determinist (A*) approach depending on precision required and patients fatigue (Randria et al., 2007a). It also uses behavioural, visual and sound information to have a better evaluation of the user and more pertinent information to therapists and prescribing doctors (Randria et al, 2007b). Simulator can be autonomously used (lever and computer screen) or integrated in a complete system using a virtual reality platform with a fixed wheelchair providing information of wheels speed (Fig. 17). It allows a very good cost-performance compromise and can be interfaced with 2D and 3D CAD software for environment conception. It can work with different controls (hand, foot, head, voice, blow…) and enable virtual tests before being in real conditions (Randria et al, 2008b).

Fig. 17. ISIDORE simulator

3. Summary

Table 1 below sums up all the particularities of each project detailed in section 2.

Projects	Year	Origin, Country	Characteristics	(1)	(2)	(3)	(4)	Info. feedback
PWMS	1993	New York, USA	Platform for manual wheelchair	No	Yes	No	No	No
Virtual Electric Power Wheelchair Driving	1993	Pittsburg Univ. / VA Healthcare System, PA, USA.	Speed control when perturbations Inside/outside environment, static and dynamic Evaluation : records position and speed of virtual wheelchair and pedestrians, number of collisions, execution time, path done.	Yes	Yes	Yes	Yes	Visual
Wheelchair User Proficiency Through Virtual Simulation	1994	OSC / Ohio Univ., OH, USA	Driving evaluation in a semi-structured world. Polarized stereovision glasses (non HMD) Spatial subdivision (Octree data structure) IR emitter DualScan stereo screen	No	No	Yes	No	Visual
Wheelchair Training	1994	Virt. Real. Lab., ORI, OR, USA	Platform « Crash » sound for collisions 3D spatialized sound Stereoscopic vision Different scenarii (user profile, environment complexity) Learning via Internet	No	Yes	Yes	No	Visual, stereoscopic, sonic, 3D
H.M2.P.H.	1998	Tours Univ, France	Automatic 2D map 3D virtual visit Databases	Yes	Yes	Yes	No	Visual
Assistive Technology Access Interfaces	1998	Ohn School for the Physically Disabled, Tel Aviv, Israel	Developing and evaluating technological assistive interfaces for people with severe physical disabilities Evaluating the ability of driving an electric wheelchair Defined evaluation scale	No	Yes	No	No	Visual
Simulator of Powered Wheelchair	1998	Research Institute, National Rehabilitation Center for the Disabled, Japon	Evaluating the ability of driving a wheelchair Mobile platform Flat screen to 110° screen Levers and behavior analysis Trajectory recording Different grounds and slopes Traffic signs	Yes	Yes	Yes	No	Visual

Projects	Year	Origin, Country	Characteristics	(1)	(2)	(3)	(4)	Info. feedback
VAHM extension for wheelchair driving simulation	2000	LASC, Université de Metz, France	Simulation platform using virtual reality Helping conception of new functionalities for mobility assistance Helping for choosing and prescribing wheelchairs Helping for learning of driving electric wheelchairs Exisiting wheelchair kinematics Sensor modelling Recording of behavior (execution time, collisions, stops in time and number…) Helping to fuzzy decision for functionalities activation	Yes	Yes	Yes	Yes	Visual
Evaluation and training for electric wheelchair driving	2000	Royal Hospital for Neuro-disability & University of East London, UK	Quantitaive and qualitative data for conception and implementation of two non-immersive environments Quantitaive and qualitative data for user evaluation Manoeuvrability and itinerary seeking capacities evaluation Collision detection	Yes	Yes	Yes	No	Visual
Automation and Robotics	2000	DSERG, Portsmouth Univ, UK	Virtual reality for elderly people	No	No	No	No	-
VEMS	2002	Limerick Univ., Ireland	Joint analysis of user performances when facing environment change and its interacting material Joint analysis of user profile and evaluation Navigation reexecution	No	Yes	No	No	Visual, haptic and sound
OCAWUP	2003	Laval and Sherbrooke Univ., QC Canada with rehab. centers	Navigation evaluation in a daily life context Standardized evaluation Determination of factors that have influence on driving capacities Modelizable environment	No	Yes	No	No	Visual
Haptic interface for accessibility	2003	Strathclyde Univ., Glasgow, UK	Wheelchair platform Virtual reality Buildings accessibility Haptic interface Surfaces changes and slopes	No	No	No	No	Haptic and visual
VRWC	2004	Clarkson	Transforming a group of	No	No	Yes	No	Visual,

Projects	Year	Origin, Country	Characteristics	(1)	(2)	(3)	(4)	Info. feedback
		Univ, New York, USA	objects Collision detection Following of slopes (set of segments) Interactions : lever, video tracker, 6-DOF platform					platform proprioceptive and vestibular
Stroke Simulator	2004	VRlab/HPC2N, Umeå Univ, Sweden	Simulator for tremors Data analysis (grounded Theory)	No	Yes	Yes	No	Visual and 3D sound
Virtual Intelligent Wheelchair	2007	CRVM, Mediterr. Univ., Marseille, France	Simulator for evaluation and training to intelligent wheelchair driving CAVE immersive interface Wheelchair dynamic model Automatic driving	Yes	No	Yes	Yes	Visual
Home electric wheelchair driving	2008	LISV, Versailles Univ., France	Wheelchair driving evaluation in a habitation Trajectory generations Criterions : distance, time, curves, manoeuvrability, driving quality	Yes	Yes	Yes	No	Numerical
WheelSim ©	2008	LifeTool, Autriche	Commercial software Coming from social, information technology, handicap and rehabilitation research Quantified driving evaluation	Yes	Yes	Yes	No	Visual and sound
ISIDORE	2008	Handibio, Toulon Univ., France and SIG, Polytech. Eng. School, Madagascar	Flatform Simulation interface Decision-making aid for therapists Rehabilitation tool Quantitative and qualitative evaluation of driving Navigation assistance through information feedback and collaborative control modes	Yes	Yes	Yes	Yes	Visual, sound and sensorial

Table 1. Summary of scientific works on wheelchair driving simulation / (1) : Numerical evaluation, (2) : Subjective evaluation (Questions), (3) : Obstacle detection, (4) : Navigation assistance

4. Conclusion

Numerous works are subjective and give priority to therapist, but lack quantified evaluation for driving capacity. Moreover, some projects are rather evolved while other are more simple but as interesting in terms of gain in conception and material costs. Thus, isometric levers use would almost have the same impact in navigation than the traditional lever of electric wheelchairs but they are most costly since very specific (Cooper et al., 2002). Other projects focus on the use of a 6-DOF platform so as to reduce inconvenience and to be more realistic (Niniss et al., 2005a). However, these gains in inconfort reduction and realism tend to be less interesting than expected (Mestre, 2004). Other use stereoscopic vision to have an improved 3D perception (Swan et al., 1994), but systems are costly and have not proved yet to bring important navigation improvement as their use quickly drive in establighing a visual discomfort or a persistant visual fatigue.

Nevertheless, conducting line of these works is visible : offering users (patients, prescribing and reahabilitation doctors, ergotherapists, …) a performant evaluation and quantification tool, easy to use, open to interface with commercial tools and with a reasonable cost to be diffused on the wider possible scale.

5. References

ADA (1990). *Americans with Disabilities Act of 1990*, U.S. Department of Justice, U.S.A.

Adelola, I.; Cox, S. & Rahman, A. (2002). Adaptable virtual reality interface for powered wheelchair training of disabled children, *Proceedings of The Fourth International Conference on Disability, Virtual Reality and Associated Technologies,* pp. 173-179, ISBN 0704911434, Veszprém, Hungary.

Adelola, I.; Rahman, A. & Cox, S. (2003). Conjoint analysis in virtual reality based powered wheelchair rehabilitation of children with disabilities, *Proceedings of the California State University Northridge 2003 Conference,* Northridge, CA, U.S.A.

Adelola, I.; Cox, S. & Rahman, A. (2003). A framework for adapting wheelchair training in virtual reality, In: *Assistive Technology - Shaping the Future*, Craddock, G.M. ; McCormack, L.P.; Reilly, R.B. & Knops, H. (Ed.), pp. 122-126, IOS Press, ISBN 9781586033736, Amsterdam, The Netherlands.

Adelola, I.; Cox, S. & Rahman A. (2005). VEMS – Training wheelchair drivers. In: *Assistive Technology: From Virtuality to Reality*, Pruski, A. & Knops, H. (Ed.), pp. 757-761, IOS Press, ISBN 1-58603-543-6, Amsterdam, The Netherlands.

Adelola, I.; Rahman, A. & Cox, S. (2005). Motivation Elements in Virtual Reality for Disabled Children - The VEMS Experience. In: *Assistive Technology: From Virtuality to Reality*, Pruski, A. & Knops, H. (Ed.), pp. 762-766, IOS Press, ISBN 1-58603-543-6, Amsterdam, The Netherlands.

Baran, E.O & Clarvoe, R. (2007). *Virtual Reality Wheelchair Program Website*. kson University, Potsdam, NY, U.S.A., http://www.clarkson.edu/~vrlab/vrwc/index.html

Bourhis, G. & Agostini Y., (1998). The VAHM Robotized Wheelchair: System Architecture and Human-Machine Interaction. *Journal of Intelligent and Robotic Systems*, Vol. 22, No. 1, pp. 39-50.

Bresler, M. (1990). Turtle Trainer: A way to evaluate power mobility readiness, *Proceedings of the RESNA 13th Annual Conference*, pp. 399-400., Washington, DC, U.S.A.

Backman, A. (2005). Colosseum3D – Authoring framework for Virtual Environments, *Proceedings of the 11th Eurographics Workshop Virtual Environments*, pp. 225-226, Aalborg, Denmark, October 2005.

Carlson, W.; Swan, E.; Stredney, D. & Blostein, B. (1994). The application of virtual wheelchair simulation to the determination of environmental accessibility and standards compliance in architectural design, *Proceedings of the Symposium on Computers & Innovative Architectural Design, The 7th International Conference on Systems Research, Informatics & Cybernetics*, Baden-Baden, Germany, August 1994.

Cooper, R.; Spaeth, D.; Jones, D.; Boninger, M.; Fitzgerald, S. & Guo, S. (2002). Comparison of virtual and real electric powered wheelchair driving using a position sensing joystick and an isometric joystick. *Medical Engineering & Physics*, Vol. 24, No. 10, 2002, pp. 703-708.

Cooper, R.A.; Ding, D.; Simpson, R.; Fitzgerald, S.; Spaeth, D.; Guo, S.; Koontz, A.M; Cooper, R.; Kim, J. & Boninger, M (2005). Virtual reality and computer-enhanced training applied to wheeled mobility: an overview of work in Pittsburgh. *Assistive Technology*, Vol. 17, No. 2, 2005, pp. 159-170.

DDA. (1995) Disability Discrimination Act 1995 (c. 50). Office of Public Sector Information (OPSI), Norwich, UK.

Dholkawala, Z.; Cox, S. & Rahman, A. (2005). An architecture for "remote monitoring" in a networked virtual environment mobility simulator (VEMS). In: *Assistive Technology: From Virtuality to Reality*, Pruski, A. & Knops, H. (Ed.), pp. 224-228, IOS Press, ISBN 1-58603-543-6, Amsterdam, The Netherlands.

Ding, D.; Cooper, R.A.; Guo, S. & Corfman, T.A. (2003). Robust velocity control simulation of a power wheelchair, *Proceedings of the RESNA 26th International Annual Conference*, Atlanta, GA, U.S.A., June 2003.

Dir, S.; Habert, O. & Pruski, A. (2008). Critères pour la configuration dynamique d'un fauteuil électrique par la réalité virtuelle, *Proceedings of the HANDICAP Conference*, Paris, France, June 2008.

Grant, M. (2003). Space requirements for wheeled mobility, *Proceedings of the* Proce*Wheelchair Simulation in Virtual Reality Workshop*, Amherst, NY, U.S.A., October 2003.

Grant, P.; Harrison, C. & Conway, B. (2004). Wheelchair simulation, *Proceedings of Cambridge Workshop on Universal Access and Assistive Technology*, Cambridge, UK, March 2004.

Grant, P.; Harrison, C. & Conway, B. (2004). The development of a wheelchair simulator to determine qualitative and quantitative performance metrics. *Journal of Assistive Technology*, Vol. 17, ISSN 1040-0435.

Harrison, A.; Derwent, G.; Enticknap, A.; Rose, F. & Attree, E. (2000). Application of virtual reality technology to the assessment and training of powered wheelchair users, *Proceedings of the 3rd International Conference Disability, Virtual Reality and Associated Technologies,* Alghero, Italy, September 2000.

Harrison, A.; Derwent, G.; Enticknap, A.; Rose, F. & Attree, E. (2002). The role of virtual reality technology in the assessment and training of inexperienced powered wheelchair users. *Disability & Rehabilitation,* Vol. 24, No. 11-12, pp. 599-606.

Hasdai, A.; Jessel, A. & Weiss, P. (1998). Use of a computer simulator for training children with disabilities in the operation of a powered wheelchair. *American Journal Occupational Therapy,* Vol. 52, No. 3, pp. 215-220.

Inman, D.P. & Loge, K. (1995). Teaching motorized wheelchair operation in virtual reality, *Proceedings of the CSUN Virtual Reality Conference,* Northridge, CA, U.S.A.

Inman, D.P.; Loge, K. & Cram, A. (2000). Teaching orientation and mobility skills to blind children using computer generated 3-D sound environments, *Proceedings of the ICAD International Conference on Auditory Display,* Atlanta, GA, U.S.A., April 2000.

Inoue, T.; Hirose, H.; Yasuo, S. & Kazunori, H. (1998). Development of a simulator of powered wheelchair, *Proceedings of the RESNA'98 Conference,* pp. 182-184, Minneapolis, MN, U.S.A., June 1998.

Inoue, T.; Sudoh, Y.; Hirose, H. & Nagumo, N. (2002). Development of a simulator for a powered wheelchair and practical use for a person with physical and mental disabilities. *Biomechanisms,* Vol. 16, pp. 183-194.

Kirby, R.L.; Swuste, J.; Dupuis, D.J.; MacLeod, D.A. & Monroe, R. (2002). Wheelchair skills test: pilot study of a new outcome measure. *Archives of Physical Medicine and Rehabilitation,* Vol. 83, pp. 10-18.

Leloup, J. (2004). *Le projet HM2PH, habitat modulaire et mobile pour personnes handicapées : spécifications d'un espace de vie adapté pour personnes en déficit d'autonomie*. PhD Thesis, Tours University, France.

Marchuk, N.D.; Ding, D. & Gaukrodger, S. (2007). Development of a virtual platform for assessment and training of power wheelchair driving , *Proceedings of the Rehabilitation Engineering & Assistive Technology Society of North America (RESNA) Conference*, Phoenix, AZ, U.S.A., 2007.

Maxhall, M.; Backman, A.; Holmlund, K.; Hedman, L.; Sondell, B. & Bucht, G. (2004). Caregiver responses to a stroke training simulator, *Proceedings of ICDVRAT2004 Conference*, Oxford, U.K., September 2004.

Mestre, D. (2004). Activités sensori-motrices : apports de la réalité virtuelle à la psychologie ergonomique, In: *Psychologie ergonomique: tendances actuelles*, Hoc, J.M.; Darses, F. (Ed.), Presses Universitaires de France, Paris, France.

Mestre, D.; Pergandi, J. & Mallet, P. (2004). Virtual reality as a tool for the development of a smart wheelchair, *Proceedings of the Virtual Reality International Conference*, Laval, France, April 2004.

Mestre, D.; Pergandi, J. & Mallet, P. (2007). Designing a navigation aid for a smart wheelchair. *AMSE Journals , Modelling C*, Vol. 67, pp. 86-95.

Niniss, H.; Nadif, A. & Bourhis, G. (2000). Système de simulation pour fauteuil roulant électrique : premiers résultats. *Journal Européen des Systèmes Automatisés*, Vol. 34, No. 6-7, pp. 799-815.

Niniss, H. & Nadif, A. (2000). Simulation of the behaviour of a powered wheelchair using virtual reality, *Proceedings of the 3rd International Conference on Disabilities, Virtual Reality and Associated Technologies*, pp. 9-14, Alghero, Italy, September 2000.

Niniss, H. & Nadif, A. (2000). Simulation System for Powered Wheelchairs : Evaluation of Driving Skills Using Virtual Reality, In: *Assistive Technology - Shaping the Future*, Craddock, G.M. ; McCormack, L.P.; Reilly, R.B. & Knops, H. (Ed.), pp. 112-116, IOS Press, ISBN 9781586033736, Amsterdam, The Netherlands.

Niniss, H. & Nadif, A. (2004). Système de simulation pour fauteuils roulants électriques: Evaluation de la commande à l'aide de la Réalité Virtuelle, *Proceedings of the HANDICAP Conference*, pp. 163-69, Paris, France, June 2004.

Niniss, H. & Inoue, T. (2006). Electric wheelchair simulator for rehabilitation of persons with motor disability, *Simpósio Brasileiro de Realidade Virtual*, Belém, Brazil.

Niniss, H. & Inoue, T. (2006). Assessment of driving skills using Virtual Reality: comparative survey on experts and unskilled users of electric wheelchairs. *Journal Technology and Disability*, Vol. 18, No. 4, pp. 217-226.

Pan, Z.; Cheok, A.D.; Yang; H.; Zhu, J. & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics*, No. 30, pp. 20-28.

Pronk, C.; de Klerk, P.; Schouten, A.; Grashuis, J.; Niesing, R. & Bangma, B. (1980). Electric wheelchair simulator as a man-machine system. *Scandinavian Journal of Rehabilitation Medicine*, Vol. 12, No. 3, pp. 129-135.

Randria, I.; Abellard, P.; Abellard, A. & Ben Khelifa, M. (2008). ISIDORE : Interface d'assistance à la SImulation, à la DécisiOn et à la Reéducation, *Proceedings of the Handicap Conference*, Paris, France, June 2008.

Randria, I.; Ben Khelifa, M.; Bouchouicha M. & Abellard, P. (2007). A comparative study of six basic approaches for path planning towards an autonomous navigation, *Proceedings of the 33rd Annual IEEE IECON Industrial Electronics Conference*, Taipei, Taiwan, November 2007.

Randria, I.; Ben Khelifa, M.; Abellard, A.; Abellard, P.; Gorce, P. & Bouchouicha M. (2007). A virtual reality application to disabled transportation simulation, *Proceedings of the Virtual Reality International Conference*, Laval, France, May 2007.

Randria, I.; Abellard, A.; Ben Khelifa, M.; Abellard, P. & Ramananstizehena P. (2008). Evaluation of trajectory applied to collaborative rehabilitation for a wheelchair driving simulator, *Proceedings of the 4th European Congress for Medical and Biomedical Engineering*, Antwerp, Belgium, November 2008.

Roussel, P. (2002). Une estimation de la diffusion des aides techniques à partir de l'enquête HID de l'INSEE. *Handicap*, No. 96, pp. 47-54.

Routhier, F.; Vincent, C.; Desrosiers, J. & Nadeau, S. (2003). Mobility of wheelchair users: a proposed performance assessment framework. *Journal Disability & Rehabilitation*, Vol. 25, No. 1, pp. 19-34.

Routhier, F.; Vincent, C.; Desrosiers, J.; Nadeau, S. & Guerette, C. (2004). Development of an obstacle course assessment of wheelchair user performance (OCAWUP): a content validity study. *Technology and Disability*, Vol. 16, No. 1, pp. 19-31.

Schmeler, M.R. (1993). *Performance Validation of a Powered Wheelchair Mobility Simulator*. Thesis (M.S.), State University of New York at Buffalo, U.S.A.

Schmeler, M.R.; Johnson, D. & Granic, J. (1993). Powered wheelchair mobility simulator, *Proceedings of the RESNA 16th Annual Conference*, pp. 357-359, Las Vegas, NV, U.S.A.

Sonar, A.; Burdick, K.; Begin, R.; Resch, E.; Thompson, E.; Thacher, E.; Searleman, J.; Fulk, G. & Carroll, J.J. (2005). Development of a virtual reality-based power wheel chair simulator, *Proceedings of the IEEE International Conference on Mechatronics and Automation*, pp. 222-229, Niagara Falls, ON, Canada, July-August 2005.

Stott, I. & Sanders, D. (2000). The use of virtual reality to train powered wheelchair users and test new wheelchair systems. *The International Journal Of Rehabilitation Research*, Vol. 23, No. 4, pp. 321-326.

Swan, E.; Stredney, D. & Carlson, W. (1994). The determination of wheelchair user proficiency and environmental accessibility through virtual simulation, *Proceedings of the Second Annual International Conference on Virtual Reality and Persons with Disabilities*, pp. 156-161, California State University, Northridge, CA, U.S.A., June 1994.

Taychouri, F.; Monacelli, E.; Hamam, Y. & Chebbo, N. (2008). Méthodologie d'analyse de l'aménagement d'un habitat pour une déambulation en fauteuil roulant, *Proceedings of the Handicap Conference*, Paris, France, June 2008.

Mechatronic Systems Applications
Edited by Annalisa Milella Donato Di Paola and Grazia Cicirelli

ISBN 978-953-307-040-7
Hard cover, 352 pages
Publisher InTech
Published online 01, March, 2010
Published in print edition March, 2010

Mechatronics, the synergistic blend of mechanics, electronics, and computer science, has evolved over the past twenty five years, leading to a novel stage of engineering design. By integrating the best design practices with the most advanced technologies, mechatronics aims at realizing high-quality products, guaranteeing at the same time a substantial reduction of time and costs of manufacturing. Mechatronic systems are manifold and range from machine components, motion generators, and power producing machines to more complex devices, such as robotic systems and transportation vehicles. With its twenty chapters, which collect contributions from many researchers worldwide, this book provides an excellent survey of recent work in the field of mechatronics with applications in various fields, like robotics, medical and assistive technology, human-machine interaction, unmanned vehicles, manufacturing, and education. We would like to thank all the authors who have invested a great deal of time to write such interesting chapters, which we are sure will be valuable to the readers. Chapters 1 to 6 deal with applications of mechatronics for the development of robotic systems. Medical and assistive technologies and human-machine interaction systems are the topic of chapters 7 to 13.Chapters 14 and 15 concern mechatronic systems for autonomous vehicles. Chapters 16-19 deal with mechatronics in manufacturing contexts. Chapter 20 concludes the book, describing a method for the installation of mechatronics education in schools.

Fax: +385 (51) 686 166
www.intechopen.com

Fax: +86-21-62489821